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TECHNICAL REPORT 150

AIR DENSITY PROFILES FOR THE ATMOSPHERE BETWEEN 30 AND 80 KILOMETERS

By

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Published By

AIR WEATHER SERVICE (MATS)
UNITED STATES AIR FORCE
JANUARY 1961

PREFACE

Detailed observational data for the upper atmosphere are needed in the analysis of various military problems. The problem of documenting and compiling the complete observational data for several meteorological parameters has long been of concern to the Air Weather Service. While this problem has been considered by a number of agencies in the United States, an adequate solution does not appear to be imminent. Meanwhile, much can be accomplished through the systematic screening of published data and by contact with the investigators who are directly involved in making atmospheric experiments.

In this report, data for 65 individual air density soundings in the mesosphere (30 to 80 km), taken during 1947-58 and at latitudes from the equator to 75°N, are presented. All values have been reduced to grams per cubic meter. Data from several rocket firings for levels above the mesopause are also included.

An understanding of the pertinent observational methods is necessary for a correct interpretation of the density data. A brief description of the four principal methods is given, along with information on the inherent observational errors.

The data for 30 to 80 km have been plotted on semi-log graph paper and density values at even-kilometer levels (2-km intervals) have been obtained. The derived mean and extreme profiles for three latitude groups and for the summer and winter half-years, and a discussion of the variability of density in the mesosphere, will be presented in a later report.

The friendly cooperation of scientists in the National Aeronautics and Space Administration and at the University of Michigan is acknowledged. In particular, we wish to thank L. M. Jones, N. W. Spencer, W. Nordberg, and J. Ainsworth for making available both published and unpublished data for many of the soundings.

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10 January 1961

EDITOR'S NOTE

The following information was received after this report had been sent to press:

a. Revised unpublished data for three rocket-pressure gage soundings (23 Oct 56, 24 Feb 58, 24 Mar 58) and previously unavailable data for four rocket-pressure gage soundings (15 Jul 58, 15 Oct 58, 20 Oct 58, 23 Nov 58), all at Fort Churchill, have been received by the author. These data have been included in the complete data sample used in computations of seasonal and latitudinal variations of density (see Section V of this report). The results of these computations will be published as *AWS Technical Report 151*.

b. The complete data for the 13 falling-sphere flights discussed in Section IV of this report have been published in a contract report of the University of Michigan (Dept. of Aero. and Astro. Eng.) in February 1961. Revisions resulting from the use of new sphere drag coefficients recently published are given for six of the flights. The changes amount to 0% at 40 km, about 5% at 60 km, and 10% at 80 to 90 km. These changes have been taken into account in the preparation of *AWS Technical Report 151*, mentioned above.

Additional copies of this report may be obtained from: Climatic Center USAF, Annex 2, 225 "D" Street, S. E., Washington 25, D. C.

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AIR DENSITY PROFILES FOR THE ATMOSPHERE BETWEEN 30 AND 80 KILOMETERS

SECTION I — INTRODUCTION

Atmospheric data at altitudes above 100,000 feet are expected to become increasingly important as certain military missile programs get further under way. A summary of some known requirements for meteorological data at levels from 100,000 to 200,000 feet has been provided in a recent report of the U. S. Naval Ordnance Laboratory [1]. This report indicates, for example, that air density data for these levels, accurate to within 5 to 20 percent, will be required for various specified programs.

In addition to fulfilling purely military requirements, data for levels in the upper atmosphere are likely to prove of value in evaluating weather in the lower atmosphere, that is, at levels in the troposphere and lower stratosphere, and vice versa. Already an apparent relation between appreciable changes in density and temperature revealed by rocket data at 45 and 65 km and an abrupt warming at balloon altitudes (20 and 30 km) has been demonstrated by Jones and others [2], for January-February 1958, over Fort Churchill, Canada.

The task of compiling systematically the upper atmosphere soundings for some of the principal meteorological elements is a tremendous one. Compared to the routinely observed rawinsonde data of the lower atmosphere, observations taken in the upper atmosphere are highly heterogeneous with respect to method of observation, and there is little continuity in the time and space distributions of the observations. In view of the importance of these data, it is becoming increasingly desirable to develop a complete and current file of the pertinent soundings, at least for selected parameters. To our knowledge, no full-length effort in this direction has been made by agencies in the United States. Excellent surveys of upper atmosphere data are available, for example [3] [4] [5], along with the innumerable reports concerned with single soundings or with series of data derived by a single method. But we have not found evidence of the existence of a highly comprehensive collection which encompasses several parameters and methods of observation and includes all of the data of the individual soundings for specific dates.

Important steps in this direction have been taken. In 1955, Newell [6] published all the rocket data at his disposal, later expanding his presentation for inclusion in the recent book Physics of the Upper Atmosphere [7]. The U. S. Navy, in 1956-57, sponsored a project [8] which would involve not only a comprehensive review of methods of high-altitude wind research, with an extensive bibliographic section, but which would include the actual wind data as well. Regrettably, the all-important second phase, the data compilation, was not completed. In the case of temperature, a recent and comparable study may be cited [9], but here again, the actual temperature soundings were not presented.

Early in 1960, plans were announced by Science Communications, Inc., Washington, D.C., under support of the Defense Atomic Support Agency and the Office of Naval Research, for the establishment of an effective clearing-house service to "facilitate the exchange of upper atmosphere data obtained by meteorological rocket researchers, data collected incidental to missile flight testing, and measurements obtained from other sources," for the altitude range 30 to 300 kilometers. A report recently issued by this group [10] indicates that a notable effort has been made toward establishing a comprehensive file of upper atmosphere observations. The data in this report are attractively presented and well documented;

however, they are not in a format which lends itself well to the addition of data acquired later, and, more important, many of the soundings are incomplete, emphasis having been placed on data for 10-km intervals of height.

From our point of view, the ideal collection of upper atmosphere observations would consist of a cumulative file of the complete data soundings, each sounding entered on a separate special form showing the date, place, and method of observation, as well as an estimate of the observational error and documentation of the source of the data. This approach has been followed by the author in compiling air density data for the atmosphere between approximately 30 and 80 kilometers. These data are reproduced in the Appendix.

In general, the data in this report were drawn from the earliest authoritative sources containing the information in tabular form. The tabular data were preferred to graphical estimates in view of the error possible in reading values from graphs; this error would only compound the already appreciable error in the original observations.

SECTION II – SCOPE

The present report is concerned with air density data for the atmosphere mainly between 30 and 80 kilometers, although most of the available data for levels above 80 km obtained by the observational methods under consideration (see Table 2) are included. This choice of altitude range has been made in view of the relative abundance of radiosonde data at levels below 30 km, and the relatively adequate documentation, in the literature, of data above 80 km. Several recent and outstanding references on densities above 80 km are listed in the bibliography [11] [12] [13] [14] [15] [16]. Indeed, it is probably correct to say that in recent years the region of the ionosphere and above has received far more attention from scientists than has the mesosphere (circa 30 to 80 km). There are two other reasons for choosing to concentrate on this realm of the atmosphere. First, appreciable molecular dissociation begins in the neighborhood of 80 km; the equation of state may no longer be applied for deriving densities without some knowledge of the molecular mass, and thus much of the available density data at the higher levels has to be considered in rather special terms. Secondly, the error in densities obtained by most methods of observation increases greatly in the vicinity of 70 to 100 km.

Table 1 outlines six principal methods which have yielded significant density data for the atmosphere between 30 and about 100 kilometers (other than radiosonde balloons, which occasionally reach beyond 30 km).

Our compilation contains most of the individual density profile data available in November 1960 for four methods of observation: rocket with pressure gages, rocket grenade, rocket and falling sphere, and searchlight. The seasonal and space distribution of the pertinent soundings, including 4 soundings obtained by miscellaneous rocket techniques (mass spectrometer, X-ray photon counter), is indicated in Table 2.

The data deduced from meteor decelerations start at relatively high levels (50 km) and incorporate errors comparable with the error in some of the poorer rocket data. Meteor-derived densities are not included in our report. Another class of data which has been excluded, owing to the apparently large observational error involved (factor of 2 or more), is the molecular densities obtained from measurements of the intensity of the zenith skylight during twilight; reference [17] is a primary source of information for this type of experiment.

For the methods under consideration, the main observational work and data reduction have been done by the Naval Research Laboratory, the University of Michigan and the Army Signal Corps, and the Air Force Cambridge Research Center. Although a large number of searchlight density profiles was obtained by Friedland [18], his data (Sacramento Peak, New Mexico, Aug-Dec 1955) are not

TABLE 1. PRINCIPAL METHODS OF DETERMINING AIR DENSITY IN THE MESOSPHERE

Basic Measurement	Method of Measurement	Altitude Range (km)	Theory	Sources of Error
Pressure on nose cone, nose tip, and/or side of rocket; rocket trajectory	Pressure gages on rockets, telemetering system	30– >100	Ambient pressure ring exists on flying rocket; theories of Taylor-Maccoll, Stone, Kopal; Rayleigh pitot-tube formula; barometric equation and equation of state	Winds; yaw; outgassing*
Time and angle of arrival of sound waves; positions of explosions; rocket trajectory	Grenades ejected from rockets; microphones; DOVAP**	30–90	Transit times depend on air temperature and wind; barometric equation and equation of state	Arrival times; effect of shock wave propagation
Drag acceleration of falling sphere ejected from rocket; sphere trajectory	DOVAP; telemetering system	15–90	Drag equation	Wind; uncertainty in coefficient of drag
Light intensity in scattering volume	Searchlight beam and receiver	10–68	Rayleigh scattering law	Height determinations; background illumination; constant of integration
Atmospheric drag on meteors; meteor mass	Photographic; radio	50–120	Öpik, Whipple, Jacchia, Herlofson	Determination of luminous efficiency
Intensity of scattered zenith skylight	Photometer	30–150	Rayleigh-Cabannes	Various (see [17])

* For more detail on the various rocket-pressure gage techniques, including a discussion of the effect of missile yaw and outgassing on presure measurements, see Reference [6].

** DOVAP refers to a missile tracking method based on the Doppler effect, velocity, and position.

TABLE 2. DISTRIBUTION OF AIR DENSITY SOUNDINGS

	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Total
Equator, 161°W		‡			1
Guam, M.I.				*******	7
White Sands, N.M.	‡o	‡oo	‡‡	‡‡‡o	11
Holloman AFB, N.M.			‡	‡‡	3
Albuquerque, N.M.		†	†††††	†††††† ††††††	18
Wallops I., Va.			oo		2
Ft. Churchill, Canada	‡‡‡ ****ooo	‡‡o	‡******	‡‡‡‡‡ *	25
Shipboard (49°-75°N)			‡‡‡‡	ooo	7
Grand Total					74

KEY: ‡ rocket with pressure gages, mass spectrometer, or photon counter

* rocket grenade

o rocket and falling sphere

† searchlight

NOTE: Of the total of 74 soundings, 9 do not contain data below 80 km.

included in our presentation, owing to the relatively low heights attained (maximum, 41 km). The results of recent searchlight experiments conducted by the Royal Aircraft Establishment in England [19] are, to our knowledge, not yet available. Preliminary rocket data for certain parameters are now becoming available from the British (Woomera, Australia) [20] and Japanese programs; detailed density data have not been published. Soviet researchers have published temperature profiles for individual rocket ascents, but the density data which are generally available are limited to mean profiles.

SECTION III — FORMAT

In view of the appreciable observational error in much of the data, some knowledge of the observational methods is required, along with at least an outline of the sources of error. Section 4 provides a concise summary of each of the four main observational methods involved, as well as brief remarks on the sources and magnitude of the observational errors, and a listing of the pertinent dates for each type of sounding. For a more detailed exposition of these matters, the individual papers cited in the bibliography should be consulted.

With regard to estimates of error, values given in Section 4 apply to each observational series as a whole. In the data tabulation estimates of error given for individual soundings may differ from the general estimates given in Section 4 if special error analyses were available. Except for the rocket grenade data, error estimates are either the actual figures given by the authors concerned or they are based on data provided by these authors.

For the rocket grenade soundings, estimates of error were available for temperatures only; on the basis of the temperature error cited, and making use of the barometric equation and the equation of state, we have made a point-by-point analysis of the corresponding error in density for a selected sounding. The results of this analysis are the basis of our estimates for the series as a whole.[1]

The density profiles in the Appendix are listed chronologically. In general, the data for levels from 20 km and above are shown. For the sake of completeness, rocket sounding data beyond 100 km are included, despite the relatively large observational errors. Special remarks regarding the treatment of the falling sphere data are included with the description of the method (see Section 4) and should be consulted for a proper appreciation of these data.

All of the density values are shown in grams per cubic meter. In order to achieve a uniform presentation and thus facilitate comparisons among the different sets of data, it was necessary to convert much of the data from other units. This applies especially to the searchlight densities, which were converted from number density cm^{-3} to $gm\ m^{-3}$ by multiplying by the mean molecular mass, assumed to be constant in the altitude range concerned, and allowing for the change in unit volume; and to several other soundings previously available only in the engineering unit, slugs ft^{-3}

SECTION IV — METHODS OF OBSERVATION AND SOURCES OF ERROR

METHOD I: Rocket with Pressure Gages.

Pressures are measured at different locations on a rocket in flight; from these, the ambient atmospheric conditions are deduced with the aid of a suitable theory relating the measured pressures with conditions in the undisturbed air about the rocket. The existence and position of the ambient pressure ring about the rocket have been ascertained both from theory and from wind tunnel tests, and by comparison of rocket data with balloon data obtained near the time and place of rocket firings. Bellows gages have been used for pressures from one atmosphere down to 20 mm of mercury (up to ~ 25 km); Pirani gages for pressures between 2 and $3X10^{-3}$ mm of mercury (to ~ 86 km); and Philips cold-cathode ionization gages for pressures between 10^{-3} (~ 93 km) and 10^{-6} mm (~ 163 km); in some cases the Havens cycle gage has been used for pressures down to about 10^{-3} mm.

The introductory statements above are based on a discussion by Newell, 1955 [6]; for a description of the method of deriving densities, the following is quoted directly from Newell:

> "Where the aero-dynamics of a continuous fluid apply, the stagnation pressure P measured at the nose of a supersonic rocket is roughly proportional to the ambient air density. In the case of a yawless rocket, this stagnation pressure is given by the Rayleigh formula, which for a diatomic gas can be put in the form . . .
>
> $$P = 0.92\, \rho\, V^2 + 0.46\, p + \ldots,$$
>
> where p and ρ are ambient pressure and density respectively, and where V is the speed of the rocket. The formula is valid [at altitudes] below about 100 kilometers. If the Mach number exceeds 3, the terms after the first on the right may be neglected and the density calculated directly. For lower Mach numbers, densities so calculated must be corrected for the effect of higher order terms. Even with angles of attack up to 10 degrees or more, the formula is good to within a few percent."

For rocket measurements of densities at altitudes above 100 km, the reader is referred to Newell's work, cited above.

[1] Fort Churchill series. Separate analysis was made for Guam soundings.

Observational Errors:

a. Instrumental error. Pressure gages are accurate to within a few percent.

b. Error due to large angle of attack of the missile (yaw). This can be due simply to missile motion, or to a combination of the missile's motion and atmospheric winds. In results obtained by the Naval Research Laboratory, the total probable errors for pressures below 75 km are less than 10%. At altitudes above 75 km, because of large missile yaw and outgassing from the gage housings and from the rocket itself, the NRL pressure data may include errors up to a factor of 2.

c. Combined error. The final density values have been judged to be good within 20%, below 100 km. At 100 km and above, most of the densities are assumed to be correct within a factor of 2. However, see the Appendix for error estimates for individual soundings; for several soundings the estimate of error is much less than 20%.

List of Observations:

a. With rockets and pressure gages.

Date	Place	Altitude Range (km) of Density Data
7 Mar 47	White Sands, N.M.[2]	69-156
22 Jan 48	White Sands	110-160
5 Aug 48	White Sands	61-69
29 Sep 49	White Sands	82-89
11 May 50	Equator, 161°W	39-66
20 Jun 50	Holloman AFB, N.M.[3]	30-72
21 Nov 50	White Sands	110
7 Aug 51	White Sands	100-220
13 Sep 51	Holloman AFB	30-60
22 Oct 52	Holloman AFB	45-90
5 Aug 53	Arctic, 62°N, 64°W	20-44
11 Aug 53	Arctic, 75°N, 94°W	20-78
19 Jul 54	Labrador Sea, 54°N, 53°W	32-43
25 Jul 54	Labrador Sea, 58°N, 55°W	25-39
23 Oct 56[5]	Ft. Churchill, Canada[4]	31-58
17 Nov 56	Ft. Churchill	20-39, 200
29 Jul 57[5]	Ft. Churchill	20-210
1 Sep 57[5]	Ft. Churchill	60-72
24 Feb 58 (0100 CST)[5]	Ft. Churchill	202
24 Feb 58 (0135 CST)[5]	Ft. Churchill	54-85
24 Mar 58[5]	Ft. Churchill	51-85
31 Oct 58	Ft. Churchill	24-188

[2] 32° 24'N, 106° 20'W

[3] 32° 54'N, 106° 05'W

[4] 58° 46'N, 94° 10'W

[5] Revised data for these dates and for 4 other rocket firings at Ft. Churchill in Jul-Nov 58 not listed here should become available by the end of 1960.

b. With rockets and miscellaneous techniques.

Mass spectrometer

Date	Place	Altitude Range (km) of Density Data
20 Nov 56	Ft. Churchill	110-220
21 Feb 58	Ft. Churchill	115-215
23 Mar 58	Ft. Churchill	110-180

X-ray photon counter

18 Oct 55	White Sands	>100

METHOD II: Rocket Grenade Observations.

The positions and times of explosions of grenades carried aloft and ejected by rockets are obtained and the times and angles of arrival of the successive sound waves are measured by an array of microphones at the ground. Densities are derived from pressures and temperatures by use of the equation of state, the pressures themselves being derived from the temperature by means of the hydrostatic equation.

The temperatures of the layers between grenades are obtained from the relationship,

$$c = (\gamma \, RT/M)^{1/2}$$

where c = velocity of sound in each layer, γ = ratio of specific heats of air, R = gas constant for air, T = temperature, and M = molecular weight.

Pressures are obtained from the equation,

$$p = p_0 \, e^{-gz/R\overline{T}}$$

where p = pressure at upper boundary of layer, p_0 = pressure at lower boundary of layer, g = average gravitational acceleration in the layer, z = thickness of layer, R = gas content, and $\overline{T}$ is the mean temperature of the layer.

Thence, density is obtained from the equation of state,

$$\rho = p/RT$$

The rocket grenade method has been found to be ineffective above approximately 90 km, where sufficient energy cannot be injected into the atmosphere to generate a sound wave that will reach the ground.

Observational Errors:

a. Error due to effect of winds on rocket trajectory, especially at low altitudes, where the rocket travels quite slowly. Corrections were made on the basis of specially measured winds at low altitudes shortly before launching of rocket.

b. Error in determination of position of grenade explosion due to yaw of rocket and to mechanical irregularity in timing of detonations. Error is small and resulting error in densities is considered negligible.

c. Error due to effect of shock wave propagation (temperature error ranges from zero at 30 km to 10 K° at 90 km). Corrections have been made by Bandeen and others [22] .

d. The chief error in temperature depends on the random errors inherent in the measurement of the times of arrival of the sound waves at the microphones. For explosions below 75 km the resulting error in temperature is generally less than ±3K°. For explosions at higher altitudes the error may increase as much as 10 times. For most of the high-altitude data, the temperature error has been estimated at 15K° [21].

In order to have some idea of the error in density, we have tentatively assumed a maximum temperature error of 3° K at 30 km, increasing to 15° K at 75 km, and have recalculated the densities for a typical good sounding at Fort Churchill (0004 CST, 27 Jan 58). The resulting error in density ranges from 2% to 8%.

The Churchill data included in this report are not those initially published in [21], but revised values provided by W. Nordberg, of the National Aeronautics and Space Administration. These include data for 2 soundings (25 Aug and 11 Dec 57) not given in [21].

List of Observations: Seventeen density profiles, as follows:

Fort Churchill	12	Nov	56
	21	Jul	57
	23	Jul	57
	12	Aug	57
	19	Aug	57
	25	Aug	57
	11	Dec	57
	14	Dec	57
	28	Jan	58
	(night)		
	28	Jan	58
	(day)		
Guam	12	Nov	58
	14	Nov	58
	20	Nov	58
	21	Nov	58
	22	Nov	58
	23	Nov	58
	25	Nov	58

Results from 12 rocket grenade soundings at White Sands, N.M., July 1950 to September 1953, reported by Stroud and others [23] are not given, as densities have not been derived from these data.

METHOD III: Rocket and Falling Sphere.

The falling-sphere method for determining density and temperature, developed by the University of Michigan, is based on measurements of the atmospheric drag acceleration of falling spheres ejected from rockets. Two procedures have been used. In the first four flights, spheres 4 feet in diameter were employed, and the results were derived from DOVAP (doppler velocity and position) trajectory measurements alone. In the later flights, a 7-inch sphere equipped with an omnidirectional accelerometer was used; by this procedure the drag acceleration is measured internally and is telemetered down to a ground station.

The density is calculated from the drag equation,

$$m a_D = \rho V^2 C_D A/2$$

where m = sphere mass,

a_D = drag acceleration,

ρ = ambient density,

V = velocity,

C_D = coefficient of drag,

A = sphere cross-sectional area.

Observational Errors:

a. Errors due to winds are neglected. According to Jones and others [2], the neglect of a vertical wind of 20 m/sec could cause a maximum error of about 5% in density, while the neglect of a horizontal wind of 100 m/sec would cause an error of 3%.

b. In the best range of the experiment (30 to 75 km), the major error is due to uncertainty in the coefficient of drag, which has been estimated to be about ± 2% for values of C_D near 1. Above 75 km, C_D and its error increase. Density is inversely proportional to C_D; thus at 30-75 km the estimated probable error is ± 2%; from 75 to 90 km the error has been estimated at ± 5%.

c. For the first 5 soundings, different estimates of error apply. Estimates based on error data provided by Bartman and Jones, 1955 [24], range from about 5% at 30 km to appreciably more than 30% at 70 km. For detailed figures, see the individual soundings.

List of Observations: Thirteen flights as follows:

14 May 52	White Sands
11 Dec 52	White Sands
23 Apr 53	White Sands
29 Sep 53	White Sands
24 Jun 55	Wallops I.
6 Jul 56	Wallops I.
2 Nov 56	Near 49°N, 48'W
4 Nov 56	Near 58°N, 47'W
10 Nov 56	Near 66°N, 58'W
25 Jan 58	Churchill
27 Jan 58	Churchill
29 Jan 58	Churchill
4 Mar 58	Churchill

For the 8 most recent flights, the data were taken from IGY Rocket Report No. 5 [25]. Values were read from the unedited tabulations, to 3 significant figures, and compared with the edited values on the graphs; adjustments were made where necessary, and data points not shown on the graphs were eliminated. The validity of this procedure has been confirmed by L. M. Jones, of the University of Michigan, in correspondence with the author. In view of the relative abundance of radiosonde data at the lower levels, only points above 20 km were extracted. With this proviso, all downleg[a] sphere data were used; upleg[a] data were used only when necessary to fill in significant gaps in the density profile or when the upleg data imparted a distinctive characteristic to the curve.

The data for 24 Jun 55, Wallops I., were taken from the University of Michigan report of 1956 [26].

The data for 14 May 52, 11 Dec 52, 23 Apr 53, and 29 Sep 53 were taken from the Michigan report of 1955 [24]. For practical reasons, in view of the especially large number of data points available, the data chosen for presentation here are for altitudes approximately one kilometer apart. The altitudes chosen are those nearest each even kilometer, as well as the bottom and top levels of each sounding.

Graphs of the data for all of these flights have been published by the Michigan researchers (see, for example, Jones and others, 1959 [2]), but we have considered it preferable to work from the tabular data, wherever possible. Any points which had to be estimated from graphs are shown in parentheses.

METHOD IV: Searchlight Observations.

Density measurements by this method are based on the Rayleigh scattering law, which relates the scattering of light from air particles to their scattering cross section and number of molecules per unit volume.

In the experiment described by Elterman [27], a searchlight beam was emitted from a point on Cedro Peak, elevation 2.36 km, about 13 miles from the Albuquerque, N.M., radiosonde station, and the scattering volume scanned at different portions of the beam by a receiving mirror installed on nearby Sandia Crest, elevation 3.54 km (see Figure 1). The choice of sites was made so as to minimize attenuation of the beam by the lower atmosphere. A clear atmosphere and an estimated loss of 5% per kilometer were assumed, in accordance with estimates for a very clear atmosphere made by General Electric searchlight engineers. The background scattering associated with airglow, the Milky Way, and miscellaneous sources was systematically measured and subtracted from the basic data.

Observational Errors:

a. Error in height determination due to setting of the elevation angles of the searchlight and receiving mirrors is $<$ 0.2 km at 50 km, corresponding to a density error of about 2%. This error is random and tends to average out.

b. Instrumentation error, $<$ 2%.

c. Error in establishing density constant of integration (from radiosonde data) is calculated at 3%.

d. Error in the background value is estimated to be that of the error inherent in the instrumentation, or close to 2%.

[a] "Upleg" and "downleg" refer to ascent and descent portions of sphere trajectory.

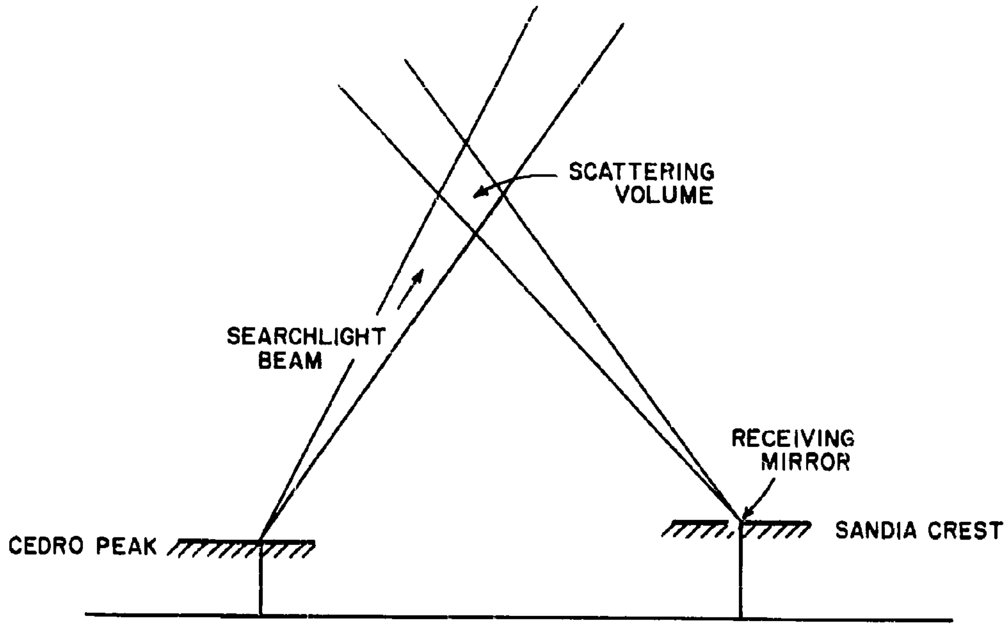

Figure 1. Sketch of Searchlight Experiment.

It is interesting to note that temperatures obtained by four different methods (radiosonde, rocket, anomalous sound propagation, and searchlight) are available for 22 October 1952. All these observations were made within a 14-hour period and within a 300-mile radius; the searchlight temperatures were derived from the searchlight densities. Elterman made a comparison of these 4 sets of temperature data and found that the temperatures obtained from the anomalous sound measurements were lower than the searchlight temperatures by 17° C, while the rocket and radiosonde temperatures compared favorably with those of the searchlight.

List of Observations: Ninety sets of measurements, yielding density profiles on 18 nights, all near Albuquerque and covering the height range 9.5 to 67.6 km. The dates are:

29 May 52	17 Sep 52	11 Oct 52
13 Jun 52	18 Sep 52	16 Oct 52
15 Jun 52	24 Sep 52	18 Oct 52
21 Jun 52	25 Sep 52	22 Oct 52 (a.m.)
22 Jun 52	26 Sep 52	22 Oct 52 (p.m.)
3 Aug 52	10 Oct 52	23 Oct 52

The observations are biased toward favorable (clear) weather conditions, with no moon in the sky. Frequent thunderstorms inhibited the observational program in July and August.

Most of the density profiles are based on several sets of measurements. The maximum separation time from the beginning of the first set of measurements to the beginning of the last set of measurements is 3 hours 30 minutes. The observational time given in this report is mid-time between the first and last sets. The time required for each individual set of measurements ranges from a few minutes to one hour.

The calculated number densities ($N \text{cm}^{-3}$), as against the smoothed densities, were extracted from Elterman's report, and these were converted to gm m^{-3} by multiplying by the mean molecular mass, and allowing for the change in unit volume.

SECTION V – CONCLUDING REMARKS

The main objective of this report has been to present the original density data; no effort has been made to interpret the data meteorologically.

The individual soundings have been plotted on semi-log graph paper and density values have been obtained for even-kilometer levels, for 2-km separations from 30 to 80 km. Tentative averages and extremes for seasons and for 3 latitude groups have been obtained; these will be revised in the near future when the final data are received for several rocket soundings now regarded as provisional. The final results, along with a discussion of the latitudinal and time variation of density in the mesosphere, will be presented in a later report.

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Appendix

DATA TABULATIONS

1. Rocket types, observation times, and station coordinates are as listed in References [43] [44] [45]. Abbreviations used are: Aer (Aerobee), Dea (Deacon), N-D (Nike Deacon), N-C (Nike Cajun), Vik (Viking). Performance characteristics of these rockets are outlined in the above references. All heights are above MSL.

2. Complete bibliographic citations of data sources are shown under "References."

3. Any density values which had to be estimated from graphs are shown in parentheses.

4. Coordinates of rocket firing locations (see Figure 2) are:

Guam, M.I.	13° 37'N, 144° 51'E
White Sands, N.M.	32° 24'N, 106° 20'W
Holloman AFB, N.M.	32° 54'N, 106° 05'W
Wallops I., Va.	37° 50'N, 75° 20'W
Fort Churchill, Canada	58° 46'N, 94° 10'W
Ocean locations:	see individual soundings

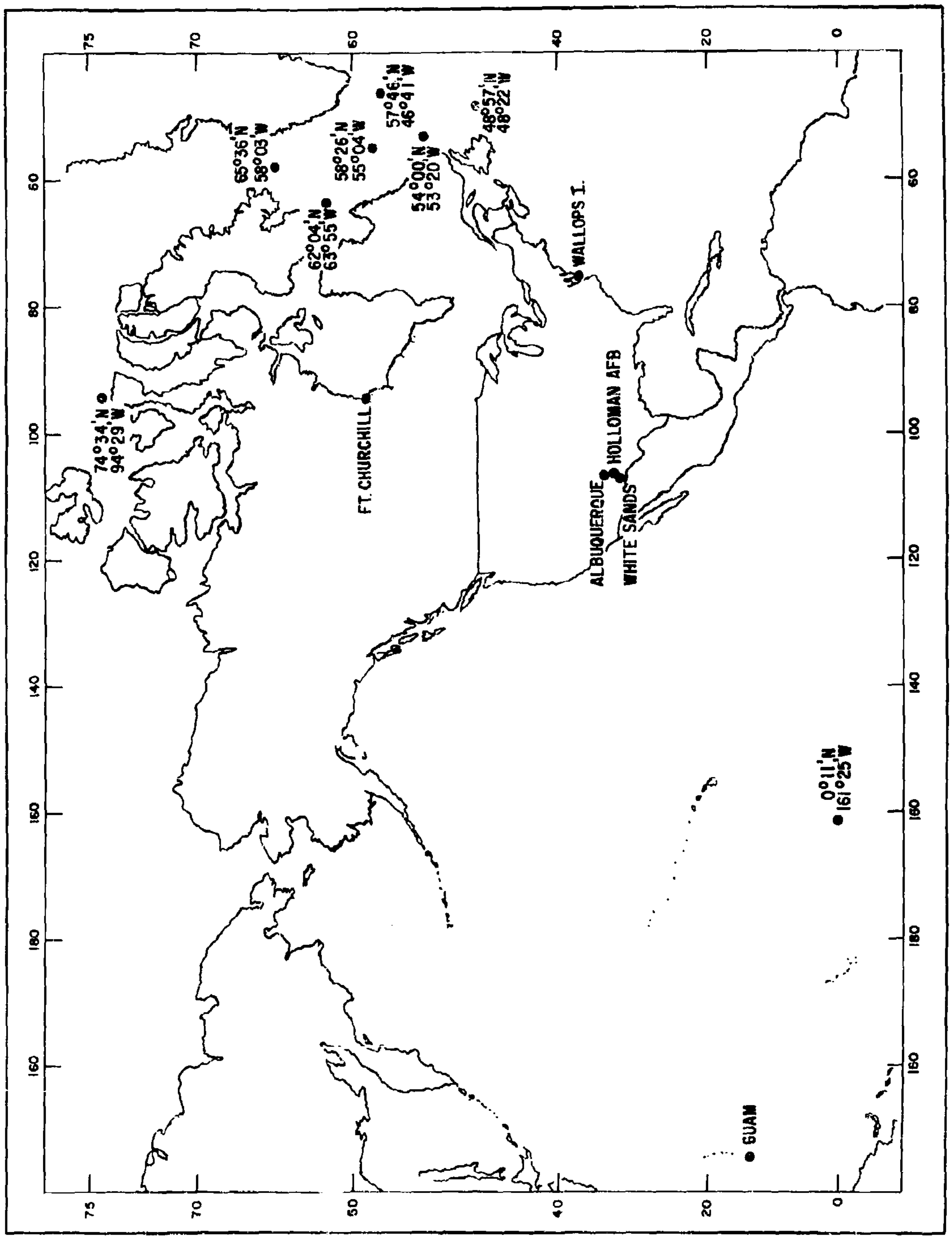

Figure 2. Approximate Location of Sites Mentioned in the Appendix.

7 Mar 47, 1123 MST

White Sands, N.M.

METHOD: Rocket (NRL V-2 21) with pressure gages

PROBABLE ERROR: < 20%, except at 156 km.

DATA SOURCES: Havens and others [28]; Newell, 1960 [7].

km	gm m^{-3}
69	0.151
70	.129
71	.114
73	.090
75	.063
76	.057
78	.042
79	.035
156	$2.0 \pm 0.5 \times 10^{-6}$

22 Jan 48, 1312 MST

White Sands, N.M.

METHOD: Rocket (NRL V-2 34) with pressure gages

ERROR: Probably subject to considerable error due to lack of altitude correction, (Champion and Minzner, 1959 [12]). Pressures from which density derived may be in error by factor of two. No corrections made for angular position of rocket relative to trajectory. (Havens and others, 1952).

THE DATA: Not reproduced here. Graph of 8 points, 110 to 160 km, available in Havens and others, 1952 [28].

5 Aug 48, 1837 MST

White Sands, N.M.

METHOD: Rocket (NRL V-2 43) with pressure gages

PROBABLE ERROR: < 20%

DATA SOURCES: Havens and others, 1952 [28] and Newell, 1960 [7].

km	gm m^{-3}
61	0.39
62	.35
64	.26
65	.24
66	.21
67	.19
68	.17
69	.14

29 Sep 49, 0958 MST

White Sands, N.M.

METHOD: Rocket (NRL V-2 49) with pressure gages

ERROR: Appreciable. No corrections made for angular position of rocket relative to trajectory (Havens and others, 1952).

DATA SOURCES: Havens and others, 1952 [28].

km	gm m^{-3}
(82)	(.01)
(85)	(.007)
(89)	(.003)

11 May 50, 1600 LCT

Equator (00° 11'N, 161° 25'W)

METHOD: Rocket (NRL Vik 4) with pressure gages

PROBABLE ERROR: < 20%

DATA SOURCES: Havens and others, 1952 [28] and Newell, 1960 [7].

km	gm m^{-3}
39	5.9
43	2.5
46	2.0
66	0.20

20 Jun 50, 0838 MST

Holloman AFB, N.M.

METHOD: Rocket (AFCRC Aer 6) with pressure gages

ERROR: In pressure, 3%; in temperature, maximum probable error estimated at 3-4% up to 60 km (± 8°K), 5-7% above 60 km (± 13°K). Maximum probable error in density < 10% (estimated by Quiroz).

DATA SOURCES: Ripley, 1957 [29]; basic pressure and temperature data in Dow and Spencer, 1953 [30] and Sicinski, Spencer, and Dow, 1954 [31].

km	gm m^{-3}	km	gm m^{-3}
30	18.6	52	0.932
32	13.8	54	.731
34	10.3	56	.573
36	7.47	58	.449
38	4.23	60	.350
40	4.22	62	.275
42	3.27	64	.213
44	2.52	66	.166
46	1.96	68	.122
48	1.53	70	.0883
50	1.19	72	.0626

21 Nov 50, 1018 MST

White Sands, N.M.

METHOD: Rocket (NRL Vik 5) with pressure gages

ERROR:

DATA SOURCES: Havens and others, 1952 [28]. One data point at 110 km available in above source; not reproduced here.

7 Aug 51, 1100 MST

White Sands, N.M.

METHOD: Rocket (NRL Vik 7) with pressure gages

ERROR: Data are average of ascent and descent and are accurate to within a factor of 2.

DATA SOURCES: Horowitz and La Gow, 1957 [32] and Newell, 1960 [7].

km	gm m^{-3}
100	2.5×10^{-4}
110	5.0×10^{-5}
120	1.2×10^{-5}
130	3.3×10^{-6}
140	1.2×10^{-6}
150	6.6×10^{-7}
160	4.3×10^{-7}
170	3.0×10^{-7}
180	2.3×10^{-7}
190	1.8×10^{-7}
210	1.1×10^{-7}
220	9.0×10^{-8}

13 Sep 51, 0437 MST

Holloman AFB, N.M.

METHOD: Rocket (AFCRC Aer 18) and pressure gages

ERROR: In pressure, 2%; maximum probable error in temperature estimated at 2% up to 50 km ($\pm 5^{\circ}$K), 3% above 50 km ($\pm 7^{\circ}$K). Maximum probable error in density $<10\%$ (estimated by Quiroz).

DATA SOURCES: Ripley, 1957 [29]; basic temperature and pressure data in Dow and Spencer, 1953 [30] and Sicinski, Spencer, and Dow, 1954 [31].

km	gm m^{-3}	km	gm m^{-3}
30	19.1	46	1.95
32	14.2	48	1.53
34	10.4	50	1.21
36	7.23	52	0.960
38	5.21	54	.755
40	4.03	56	.594
42	3.13	58	.466
44	2.46	60	.365

14 May 52, 1816 MST

White Sands, N.M.

METHOD: Rocket (SC Aer 23) and falling sphere

PROBABLE ERROR: < 10%, 50-55 km; < 20%, 56-60 km; 35% at 64 km; 75% at 66 km.

DATA SOURCES: Bartman and Jones, 1955 [24]; Bartman and others, 1956 [33].

km	gm m^{-3}	km	gm m^{-3}
50.4	1.16	58.9	.360
50.9	1.07	60.0	.380
52.1	0.897	60.9	.405
52.9	.820	61.9	.236
54.1	.706	63.1	.260
54.9	.675	63.9	.363
56.0	.511	65.0	.0469
57.1	.429	66.0	.0541
57.9	.449		

29 May - 23 Oct 52, (near) Albuquerque, N.M. METHOD: Searchlight

PROBABLE ERROR: ≤ 5% DATA SOURCES: Elterman, 1954 [27].

km	29 May 52* 0100 MST	13 Jun 52 2225 MST	15 Jun 52 2328 MST	21 Jun 52 2245 MST	22 Jun 52 2245 MST	3 Aug 52 0303 MST
	gm m^{-3}					
20.7	80.6	88.8	92.2	86.4	85.4	82.1
22.5	61.4	60.5	57.1	58.6	61.4	59.5
24.6	45.5	42.2	40.6	43.2	45.0	42.2
26.0	35.4	33.7	32.3	34.4	34.2	33.2
27.5	27.5	26.1	25.2	26.3	26.1	25.8
29.8	19.2	17.9	17.8	18.2	17.6	17.5
31.9	13.9	13.2	13.1	13.2	12.9	12.9
34.2	9.65	9.07	9.12	9.02	9.31	9.02
37.9	4.71	4.77	5.71	5.33	5.18	5.14
41.3	3.72	3.18	3.87	3.48	3.34	3.10
45.5	1.89	1.90	1.77	1.71	1.92	1.75
50.8	0.960	1.08	0.955	0.859	0.941	0.998
55.3	.624	0.590	.595	.552	.652	.562
57.9	.538	.442	.453	.445	.381	.456
60.7	.335	.359	.323	.308	.235	.387
64.0	.232	.288	.242	.171	.194	.282
67.6	.203	.143	.162	.145	.139	.219

* Times given are mid-time between sets of measurements. See section on observational methods for further discussion.

29 May - 23 Oct 52, (near) Albuquerque, N.M. METHOD: Searchlight

PROBABLE ERROR: ≤ 5% DATA SOURCES: Elterman, 1954 [27].

	gm m^{-3}					
km	17 Sep 52 2118 MST	18 Sep 52 2333 MST	24 Sep 52 2253 MST	25 Sep 52 2320 MST	27 Sep 52** 0020 MST	10 Oct 52 2020 MST
20.7	84.5	95.0	86.4	88.8	82.6	90.7
22.5	59.0	60.5	58.6	61.9	60.5	60.0
24.6	42.1	44.1	41.8	43.3	42.3	43.4
26.0	33.1	35.2	33.9	34.6	32.8	34.6
27.5	25.8	27.1	26.9	26.5	25.8	26.9
29.8	17.9	18.9	18.4	18.2	17.2	18.2
31.9	13.0	13.7	13.3	13.0	12.8	13.5
34.2	9.07	9.79	8.93	9.07	8.88	9.74
37.9	5.28	5.95	5.04	5.14	5.04	5.90
41.3	3.23	2.12	3.21	3.20	3.08	3.40
45.5	1.88	1.90	1.65	1.74	1.84	1.97
50.8	0.888	0.979	0.859	0.912	0.926	1.06
55.3	.643	.576	.485	.533	.590	0.710
57.9	.412	.468	.387	.406	.406	.523
60.7	.334	.342	.257	.315	.299	.474
64.0	.229	.170	.157	.213	.230	.348
67.6	.200	.168	.099	.158	.192	.272

** Elterman lists date for this sounding as 26 Sep 52, according to the time of the first set of observations. Mid-time between sets of observations falls on the 27th.

29 May - 23 Oct 52, (near) Albuquerque, N.M. METHOD: Searchlight

PROBABLE ERROR: ≤ 5% DATA SOURCES: Elterman, 1954 [27].

km	gm m^{-3} 11 Oct 52 1945 MST	16 Oct 52 2115 MST	18 Oct 52 2025 MST	22 Oct 52 0255 MST	22 Oct 52 2215 MST	23 Oct 52 2220 MST
20.7	89.3	89.3	87.4	87.8	86.4	89.3
22.5	61.9	60.5	59.5	58.1	59.0	61.0
24.6	45.2	43.4	42.3	41.3	42.0	43.7
26.0	35.4	34.3	34.5	32.7	33.7	35.0
27.5	27.0	26.2	26.8	25.3	26.2	27.0
29.8	18.7	18.5	18.2	17.8	17.9	18.6
31.9	13.9	12.9	13.2	12.9	13.2	13.5
34.2	9.84	9.22	9.26	9.02	9.26	9.55
37.9	6.00	5.33	5.38	5.18	5.38	5.52
41.3	3.71	3.12	3.39	3.26	3.34	3.43
45.5	2.02	1.72	2.00	1.78	1.86	1.92
50.8	1.11	0.878	0.946	0.912	1.00	1.07
55.3	0.687	.423	.653	.581	0.566	0.619
57.9	.614	.385	.457	.444	.444	.469
60.7	.542	.273	.381	.269	.346	.396
64.0	.303	.276	.217	.192	.256	.266
67.6	.214	.164	.132	.143	.204	.168

22 Oct 52, 0721 MST

Holloman AFB, N.M.

METHOD: Rocket (AFCRC Aer 31) with pressure gages

ERROR: Error data not located. It is believed error would be comparable to that for 13 Sep 51, i.e., < 10%.

DATA SOURCES: Ripley, 1957 [29].

km	gm m^{-3}	km	gm m^{-3}
45.1	1.62	68.0	.107
46.1	1.44	70.0	.082
47.0	1.29	72.6	.058
48.1	1.92	73.3	.052
49.0	1.00	74.0	.046
50.1	0.890	75.0	.041
51.0	.783	76.0	.035
52.1	.709	77.0	.0310
53.0	.629	78.0	.026
54.3	.558	81.0	.017
55.0	.512	81.3	.015
56.0	.419	82.4	.013
57.0	.410	83.7	.012
58.0	.359	84.9	.0087
59.0	.312	85.3	.0080
60.0	.277	85.7	.0073
61.2	.244	86.0	.0073
62.0	.218	86.4	.0070
63.4	.186	87.4	.0056
64.3	.176	87.8	.0056
65.0	.152	88.5	.0045
66.0	.137	89.5	.0035
67.0	.123	89.7	.0031

11 Dec 52, 1647 MST

White Sands, N.M.

METHOD: Rocket (SC Aer 29) and falling sphere

PROBABLE ERROR: < 5%, 35-55 km; < 10%, 56-61 km; < 20%, 62-65 km; 25%, 69 km; 75%, 75 km.

DATA SOURCES: Bartman and Jones, 1955 [24]; Bartman and others, 1956 [33].

km	gm m^{-3}	km	gm m^{-3}
34.1	9.85	54.9	.464
35.0	9.54	56.2	.465
35.9	7.32	57.1	.541
36.9	5.77	57.9	.588
38.1	5.36	58.8	.458
39.1	3.72	60.2	.385
40.0	3.77	61.0	.230
40.9	3.12	61.9	.278
41.9	2.90	62.8	.104
42.9	2.10	64.1	.0184
44.0	2.21	65.4	.0804
45.1	1.69	66.2	.127
45.9	1.48	67.1	.147
47.1	1.63	67.9	.0840
47.9	1.41	69.1	.169
49.2	0.964	69.9	.0861
50.1	.851	71.1	.141
50.9	.680	71.9	.0727
52.2	.758	74.3	.0221
53.1	.598	75.0	.00572
54.0	.508		

23 Apr 53, 1233 MST

White Sands, N.M.

METHOD: Rocket (SC Aer 30) and falling sphere

PROBABLE ERROR: <5%, 37-58 km; <10%, 59-63 km; <20%, 64-69 km; <30%, 70-79 km; <68%, 81 km.

DATA SOURCES: Bartman and Jones, 1955 [24]; Bartman and others, 1956 [33].

km	gm m^{-3}	km	gm m^{-3}
36.8	5.26	59.1	.310
37.0	5.16	60.1	.256
37.9	4.77	61.2	.269
39.1	3.99	62.2	.269
40.1	3.33	62.8	.258
41.1	3.26	63.7	.271
41.9	2.70	64.8	.0722
43.1	2.44	65.9	.121
43.9	2.00	66.9	.159
45.2	1.62	67.9	.0758
46.1	1.70	68.9	.125
47.0	1.64	69.9	.0644
47.9	1.34	70.9	.105
48.9	1.30	71.9	.0660
49.8	1.05	72.9	.0294
50.8	0.912	73.8	.123
51.8	.892	75.3	.0430
52.9	.624	76.2	.0747
53.9	.768	77.6	.0588
54.9	.639	78.6	.0168
56.0	.462	79.0	.0313
57.0	.447	79.9	.0171
58.0	.424	80.8	.0321

5 Aug 53, 2154Z

Arctic, 62° 04'N, 63° 55'W

METHOD: Rocket (NRL Dea 1) with pressure gages

PROBABLE ERROR: 24-32 km, <10%; 36-44 km, <20%.

DATA SOURCES: La Gow and Ainsworth, 1956 [34]; Newell, 1960 [7].

km	gm m^{-3}
20	88.0
24	48.3
28	26.2
32	13.9
36	7.60
40	4.30
44	2.52

11 Aug 53, 1709 Z

Arctic, 74° 34'N, 94° 29'W

METHOD: Rocket (NRL Dea 4) with pressure gages

PROBABLE ERROR: 20-32 km, <10%; 36-78 km, <20%.

DATA SOURCES: La Gow and Ainsworth, 1956 [34]; Newell, 1960 [7].

km	gm m^{-3}
20	90
24	49.3
28	26.5
32	14.3
36	7.80
40	4.34
44	2.46
72	0.076
78	0.030

29 Sep 53, 1350 MST

White Sands, N.M.

METHOD: Rocket (SC Aer 31) and falling sphere

PROBABLE ERROR: < 10%, 31-51 km; < 30%, 53-54 km.

DATA SOURCES: Bartman and Jones, 1955 [24]; Bartman and others, 1956 [33].

km	gm m^{-3}	km	gm m^{-3}
31.3	16.2	43.0	3.20
32.0	15.2	44.1	2.45
33.0	9.64	45.0	2.59
34.0	8.30	46.0	2.08
35.0	9.32	47.1	1.87
35.9	7.27	47.9	1.62
37.0	6.80	49.0	1.26
38.0	4.4	50.0	0.598
39.0	4.8	51.0	1.88
40.0	4.13	51.9	1.07
41.0	3.48	53.0	0.464
42.1	3.54		

Upleg data (selected level)

53.6	0.423

19 Jul 54, 1600 Z

Labrador Sea, 54° 00'N, 53° 20'W

METHOD: Rocket (NRL Dea 7) with pressure gages

PROBABLE ERROR: 8% at 32 km, increasing to 18% at 43 km.

DATA SOURCES: La Gow and Ainsworth, 1956 [34].

km	gm m^{-3}
31.7	(14)
32.1	(13) *
32.8	(12)
34.1	(9.6)
35.6	(7.8)
36.8	(6.4)
38.6	(5.1) *
39.9	(4.1) *
41.3	(3.3)
42.7	(2.9) *

* Upleg data

25 Jul 54, 1845 Z

Labrador Sea, 58° 26'N, 55° 04'W

METHOD: Rocket (NRL Dea 10) with pressure gages

PROBABLE ERROR: 6% at 25 km, increasing to 12% at 39 km.

DATA SOURCES: La Gow and Ainsworth, 1956 [34].

km	gm m^{-3}
24.9	(42)
26.1	(34) *
26.9	(29)
27.9	(25) *
31.6	(14)
33.0	(12)
34.7	(9.0) *
36.9	(6.7)
38.8	(5.4) *

* Upleg data

24 Jun 55, 1304 EST

Wallops Island

METHOD: Rocket (DAN 2) and falling sphere

PROBABLE ERROR: <15%, 30-40 km; < 7%, 41-50 km; < 5%, 51-80 km.

DATA SOURCES: Jones and Bartman, 1956 [26].

km	gm m^{-3}	km	gm m^{-3}	km	gm m^{-3}	km	gm m^{-3}
30.5	18.0	45.8	2.07	59.2	.385	71.5	.0665
31.1	16.4	47.1	1.50	59.8	.331	72.0	.0557
32.2	12.2	47.8	1.37	60.4	.301	72.5	.0716
32.8	11.1	48.5	1.51	60.9	.318	73.0	.0567
34.0	9.69	49.1	1.32	61.5	.255	73.5	.0541
35.2	9.02	49.8	1.23	62.1	.251	74.0	.0504
36.5	6.44	50.4	1.01	62.7	.239	74.5	.0403
37.1	6.70	51.1	0.979	63.3	.206	75.0	.0349
37.8	5.52	51.7	0.985	63.9	.209	75.5	.0434
38.4	4.46	52.4	.825	64.4	.178	75.9	.0279
39.1	4.98	53.0	.758	65.0	.162	76.4	.0390
39.8	4.75	53.6	.665	65.6	.164	76.9	.0301
40.5	3.50	54.3	.644	66.1	.151	77.3	.0234
41.1	3.20	54.9	.572	66.7	.129	77.8	.0302
41.8	2.81	55.5	.552	67.2	.123	78.3	.0247
42.5	3.38	56.1	.521	67.8	.118		
43.1	2.76	56.7	.485	68.8	.101	Upleg data	
43.8	2.33	57.4	.456	69.4	.0866	(sel. levels)	
44.5	2.22	58.0	.418	70.4	.0716	79.0	.0253
45.1	1.97	58.6	.385	70.9	.0742	79.5	.0224

18 Oct 55, 1549 MST

White Sands, N.M.

METHOD: Rocket (NRL Aer 34) with X-ray photon counter

ERROR: Possibly > 200%, according to Champion and Minzner, 1959.

THE DATA: Not reproduced here. Above 100 km. Graph of data available in Byram and others, 1956 [35].

6 Jul 56, 1300 EST

Wallops Island

METHOD: Rocket (AM N-C 6.01) and falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-87 km.

DATA SOURCES: Jones and others, 1959 [25].

km	gm m^{-3}
49.0	1.44
50.9	1.17
52.8	0.905
55.6	.667
56.5	.652
57.4	.599
58.3	.474
60.1	.407
61.0	.370
61.9	.331
62.8	.311
63.6	.259
64.5	.238
65.3	.210
66.2	.183
67.1	.166
67.9	.139
68.7	.129
70.4	.108
72.1	.0822
72.9	.0863

Upleg data (sel. levels)

km	gm m^{-3}
73.1	.0651
73.9	.0718
74.8	.0527
76.4	.0454
77.3	.0417
78.1	.0313
79.7	.0206
80.5	.0226
81.3	.0258
82.0	.0268
85.2	.00905
86.7	.00850

23 Oct 56, 0240 CST

Ft. Churchill

ERROR: Data are preliminary; revised data should become available in late 1960.

DATA SOURCE: Spencer and others, 1958 [36].

km	gm m^{-3}
31	(17)
35	(9)
37.5	(6)
40	(4)
42.5	(3)
45	(2)
47.5	(1.4)
50	(1)
52.5	(0.7)
55	(0.5)
57.5	(0.4)
60	(0.25)

2 Nov 56, 1540 Zone 3 Time

North Atlantic, 48° 57'N, 48° 22'W

METHOD: Rocket (AM N-C 6.09) and falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-81 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}
20.1	92.2
20.5	86.1
21.0	80.0
21.9	66.4
22.5	62.1
23.1	54.5
23.6	48.7
24.3	44.5
25.0	40.1
25.7	34.8
26.5	30.6
(28.)	(28.)
29.1	20.0
30.0	17.5
31.0	14.4
32.0	12.4
33.0	10.7
34.0	9.04
35.0	7.70
36.1	6.56
37.1	5.51
38.2	4.70
39.3	3.99
40.3	3.41
41.4	2.91
42.4	2.52
43.5	2.14
44.6	1.80
45.7	1.54
46.7	1.33
48.9	1.02
49.9	0.885

km	gm m^{-3}
51.0	.755
52.0	.681
53.1	.567
54.1	.487
55.1	.423
56.1	.386
(57.)	(.32)
(58.)	(.3)
59.1	.294
61.1	(.20)
62.1	.194
63.1	.190
64.0	.178
65.0	.124
66.0	.113
67.8	.0785
68.8	.0657
70.6	.0414
71.5	.0506
72.4	.0720
75.1	.0375

Upleg data
(sel. levels)

km	gm m^{-3}
(74.)	(.1)
75.2	(.040)
(76.)	(.018)
79.7	.0254
80.6	.0167
81.4	.0220

4 Nov 56, 1554 Zone 3 Times

North Atlantic, 57° 46'N, 46° 41'W

METHOD: Rocket (AM N-C 6.10) and falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-90 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}
20.2	99.4
20.7	92.2
21.1	85.6
(22.)	(67.)*
(24.)	(51.)*
(26.)	(38.)*
26.9	30.4
27.8	24.7
28.9	21.2
29.8	19.0
30.9	15.6
32.0	12.4
34.3	8.58
36.6	5.92
37.8	
39.0	3.95
40.2	3.19
44.4	2.61
42.6	2.28
43.8	1.87
45.1	1.57
46.3	1.32
47.5	1.11
48.7	0.909
49.9	(.73)
51.2	.661
52.4	.564
53.6	.482
54.9	.558
56.1	.396

* From radiosonde data obtained at nearby station.

km	gm m^{-3}
57.3	.323
58.5	.313
59.7	.214
60.9	.194
62.1	.188
63.3	.167
64.5	.140
65.7	.0928
66.9	.0850
68.1	.0750
70.4	.0528
71.6	.0501
72.7	.0497
73.9	.0286
75.0	.0284
76.2	.0211
78.5	.0174
79.7	.0182
81.8	.0100
82.8	.00637
84.8	.00638
85.8	.00583
87.8	.00522

Upleg data
(sel. levels)

km	gm m^{-3}
90.2	.00311

10 Nov 56, 1117 Zone 4 Time

Davis Strait, 65° 36'N, 58° 03'W

METHOD: Rocket (AM N-C 6.12) with falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-90 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}	km	gm m^{-3}
20.3	75.3	(68.)	(.076)
(22.5)	(50.)	(69.)	(.066)
26.5	27.0	(70.)	(.060)
28.6	19.0	71.3	.0431
29.8	15.8	72.5	.0415
31.0	12.8	73.6	.0311
32.2	10.4	74.8	.0269
33.4	8.35	76.0	.0316
34.7	6.64	77.1	.0209
35.9	5.64	(78.)	.025)
37.2	4.55	79.4	.0233
38.5	3.69	80.5	.0241
39.8	3.08	81.6	.0230
41.1	2.52	83.8	.0188
42.5	2.09	84.7	(.0068)
43.8	1.70	85.8	.00977
45.2	1.37	86.9	.00936
46.5	1.19	90.0	.00856
47.8	0.938		
49.1	.748	Upleg data (sel. levels)	
50.4	(.63)		
51.7	(.52)		
53.0	.448	76.7	.0172
54.3	.397	79.1	.0162
55.5	.316		
58.0	.253		
59.3	.220		
(61.)	(.17)		
(62.)	(.14)		
63.0	.127		
64.2	.115		
65.4	.101		
66.6	.0858		

12 Nov 56, 0548 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.01) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
19.0	94.3
19.5	80.8
21.5	59.1
23.5	43.1
25.5	31.3
27.5	22.5
29.5	16.0
31.5	11.6
33.5	8.33
35.5	6.06
37.5	4.52
39.5	3.20
41.5	2.40
43.5	1.81
45.5	1.33
47.5	.996
49.5	.781
51.5	.620
53.5	.454
55.5	.357
57.5	.288
59.5	.230

17 Nov 56, 1048 CST

Ft. Churchill, Canada

METHOD: rocket (NN Aer 3.12F) with pressure gages

PROBABLE ERROR: < 3%, except at 200 km

DATA SOURCES: Ainsworth and others [37]; Newell, 1960 [7].

km	gm m^{-3}
20	81.1
22	59.5
24	43.7
26	32.1
28	23.6
30	17.2
32	12.6
34	9.24
36	6.78*
39	4.28*
200*	$3.6 \, {}^{+3.9}_{-1.5} \times 10^{-7}$

* From Reference 7.

20 Nov 56, 2321 CST

Ft. Churchill, Canada

METHOD: Rocket (NRL Aer 43) with mass spectrometer

ERROR: Below 170 km, maximum error is factor of 2; above 170 km, maximum error is factor of 3; probable error is less.

DATA SOURCES: Townsend and Meadows, 1958 [39]; Meadows and Townsend, 1960 [40].

Data not tabulated here

21 Jul 57, 2216 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.02) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
23.6	52.3
24.1	45.0
26.1	32.9
28.1	24.2
30.1	17.8
32.1	13.3
34.1	9.75
36.1	7.27
38.1	5.46
40.1	4.14
42.1	3.17
44.1	2.44
46.1	1.90
48.1	1.48
50.1	1.18
52.1	.933
54.1	.739
56.1	.586
58.1	.463
60.1	.369
62.1	.292
64.1	.231
66.1	.181
68.1	.140
70.1	.107
72.1	.0800
74.1	.0591
76.1	.0433
78.1	.0313
80.1	.0224
82.1	.0158

23 Jul 57, 2330 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.03) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
31.4	15.4
31.9	13.2
33.9	9.88
35.9	7.47
37.9	5.72
39.9	4.41
41.9	3.35
43.9	2.55
45.9	1.96
47.9	1.51
49.9	1.18
51.9	.918
53.9	.731
55.9	.579
57.9	.457
59.9	.360
61.9	.284
63.9	.223
65.9	.173
67.9	.134
69.9	.104
71.9	.0803
73.9	.0610
75.9	.0457
77.9	.0334
79.9	.0240
81.9	.0169

29 July 57, 1600 CST

Ft. Churchill, Canada

METHOD: Rocket (NN Aer 3.13F)
with pressure gages

PROBABLE ERROR: < 5% below 100 km;
± 30% at 100 km and above (Newell, 1960)

DATA SOURCES:
A. Ainsworth and others, unpublished [37]
B. Newell, 1960 [7]
La Gow and others, 1958 [38]
Horowitz and La Gow, 1958 [41]

km	A gm m^{-3}	B gm m^{-3}	km	A gm m^{-3}	B gm m^{-3}
20	91.2	90.0	64	.227	.227
22	66.6		65		.199
24	49.0	49.5	66	.177	.175
26	36.4		67		.152
28	26.7	27.0	68	.134	.132
30	19.8		69		.113
32	14.7	14.7	70	.0984	.097
34	10.9		72	.0764	
36	8.04	8.20	74	.0571	
38	5.99		76	.0405	
39		5.32	78	.0290	
40	4.50	4.63	80	.0215	
42	3.44		82	.0157	
43		3.07	100		7.2×10^{-4}
44	2.65	2.68	110		1.3×10^{-4}
46	2.06	2.08	120		2.6×10^{-5}
48	1.63	1.62	130		6.4×10^{-6}
50	1.25		140		3.0
52	0.958	0.990	150		1.9
54	.760		160		1.4
56	.607	.610	170		1.1
58	.485		180		8.9×10^{-7}
60	.385	.385	190		7.9
61		.337	200		7.0
62	.298	.296	210		6.2

12 Aug 57, 1000 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.04) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
33.7	11.0
34.2	9.51
36.2	7.11
38.2	5.33
40.2	4.02
42.2	3.02
44.2	2.29
46.2	1.80
48.2	1.43
50.2	1.12
52.2	.871
54.2	.688
56.2	.547
58.2	.426
60.2	.335
62.2	.260
64.2	.201

19 Aug 57, 2030 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.05) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
31.8	14.1
32.3	12.2
34.3	9.20
36.3	6.76
38.3	5.03
40.3	3.82
42.3	2.91
44.3	2.24
46.3	1.71
48.3	1.30
50.3	1.02
52.3	.803
54.3	.639
56.3	.508
58.3	.402
60.3	.313
62.3	.243
64.3	.191
66.3	.150
68.3	.118
70.3	.0915
72.3	.0689
74.3	.0512
76.3	.0377
78.3	.0274
80.3	.0196
81.3	.0165

25 Aug 57, 0808 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 2.06) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Nordberg, 1960 (unpublished)

km	gm m^{-3}	km	gm m^{-3}
32.8	12.2	68.3	.109
34.3	9.07	70.3	.0838
36.3	6.75	72.3	.0630
38.3	5.02	74.3	.0459
40.3	3.76	76.3	.0332
42.3	2.85	78.3	.0236
44.3	2.17	80.3	.0165
46.3	1.66	82.3	.0115
48.3	1.29	84.3	.00792
50.3	1.00	86.3	.00543
52.3	.782	88.3	.00387
54.3	.610		
56.3	.475		
58.3	.371		
60.3	.289		
62.3	.224		
64.3	.178		
66.3	.141		

1 Sep 57, 1628 CST

Ft. Churchill, Canada

METHOD: Rocket (AM Aer 4.01) with pressure gages

ERROR: Data are preliminary; revised data should become available fall 1960.

DATA SOURCE: Spencer and others, 1958 [36].

km	gm m^{-3}
60	(0.4)
62.5	(0.3)
65	(0.2)
67.5	(0.14)
70	(0.09)
72	(0.075)

11 Dec 57, 2200 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.07) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Nordberg, 1960 (unpublished)

km	gm m^{-3}	km	gm m^{-3}
20.8	71.3	56.3	.291
22.3	51.9	58.3	.219
24.3	37.4	60.3	.166
26.3	26.6	62.3	.122
28.3	18.9	64.3	.0909
30.3	13.3	66.3	.0685
32.3	9.33	68.3	.0522
34.3	6.56	70.3	.0391
36.3	4.64	72.3	.0316
38.3	3.32	74.3	.0270
40.3	2.41	76.3	.0215
42.3	1.81		
44.3	1.37		
46.3	1.05		
48.3	.807		
50.3	.620		
52.3	.481		
54.3	.377		

14 Dec 57, 1500 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.08) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
29.5	17.0
30.0	14.3
32.0	10.1
34.0	7.23
36.0	5.21
38.0	3.78
40.0	2.73
42.0	1.96
44.0	1.43
46.0	1.08
48.0	.810
50.0	.613
52.0	.476
54.0	.370
56.0	.290
58.0	.227
60.0	.178
62.0	.130
64.0	.0936
66.0	.0713
68.0	.0550
70.0	.0423
72.0	.0325
74.0	.0248
76.0	.0188
78.0	.0141
80.0	.0106
82.0	.00788
84.0	.00585
86.0	.00433

25 Jan 58, 1312 CST

Ft. Churchill, Canada

METHOD: Rocket (AM N-C 6.02) and falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-90 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}	km	gm m^{-3}
20.3	82.7	57.5	.255
20.8	73.6	58.8	.220
21.4	68.4	60.1	.183
22.9	54.3	61.4	.161
23.7	48.1	62.7	.135
24.5	42.2	64.0	.112
28.7	22.0	65.3	.103
30.0	17.6	66.6	.0818
31.2	14.1	69.1	.0653
33.9	8.95	70.3	.0506
35.3	6.93	71.6	.0450
36.6	5.52	72.8	.0411
38.0	4.34	74.0	.0303
39.5	3.52	75.3	.0267
40.9	2.77	76.5	.0254
42.3	2.19	77.6	.0178
43.7	1.74	78.8	.0167
45.1	1.38	80.0	.0145
46.5	1.12	81.2	.0105
47.9	0.880	82.3	.0115
49.3	.764	83.5	.0105
50.7	.631	84.6	.00601
52.1	.525	85.7	.00702
53.4	.429	86.8	.00651
54.8	.348	87.9	(.0047)
56.2	.294	90.1	(.0040)

27 Jan 58, 0004 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 1.09) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
26.0	33.8
27.5	24.4
29.5	17.4
31.5	12.7
33.5	9.02
35.5	6.38
37.5	4.53
39.5	3.23
41.5	2.33
43.5	1.70
45.5	1.26
47.5	.946
49.5	.713
51.5	.542
53.5	.415
55.5	.319
57.5	.246
59.5	.189
61.5	.145
63.5	.111
65.5	.0856
67.5	.0658
69.5	.0506
71.5	.0386
73.5	.0288
75.5	.0213
77.5	.0157
79.5	.0120
81.5	.00937
83.5	.00726
85.5	.00558

27 Jan 58, 1249 CST

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 2.10) - grenade

ERROR: Maximum, 2% - 8% (estimated by Quiroz)

DATA SOURCE: Original listing -- Bandeen and others, 1959 [21]; final listing -- Nordberg, 1960 (unpublished).

km	gm m^{-3}
29.7	18.7
30.2	15.9
32.2	11.5
34.2	8.05
36.2	5.65
38.2	3.98
40.2	2.84
42.2	2.07
44.2	1.54
46.2	1.15
48.2	.872
50.2	.666
52.2	.510
54.2	.391
56.2	.302
58.2	.233
60.2	.180
62.2	.139
64.2	.111
66.2	.0867
68.2	.0670
70.2	.0515
72.2	.0394
74.2	.0293
76.2	.0214
78.2	.0161
80.2	.0123
82.2	.00968
84.2	.00760
86.2	.00590

27 Jan 58, 1249 CST*

Ft. Churchill, Canada

METHOD: Rocket (SM Aer 2.10) and falling sphere

PROBABLE ERROR: <2%, 20-75 km; <5%, 76-90 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}	km	gm m^{-3}
20.3	99.5	60.4	.146
21.0	79.7	63.1	.104
22.7	54.6	64.5	.0926
23.6	45.1	65.9	.0734
24.7	37.6	67.2	.0617
25.8	29.4	69.8	.0421
27.1	24.6	71.1	.0368
29.7	12.8	72.4	.0318
32.5	8.35	73.7	.0251
34.0	6.65	75.0	.0192
35.5	4.74	76.2	.0157
37.0	3.79	77.4	.0136
40.0	2.20	78.7	.0123
41.5	1.79	79.9	.0112
43.0	1.44	81.1	.00972
44.5	1.20	83.5	.00550
46.0	0.965	84.6	.00480
47.5	.769	85.8	.00471
48.9	.659	87.0	.00435
50.4	.539	88.1	.00329
51.9	.447	89.2	.00219
53.3	.367	90.3	.00175
59.0	.181		

29 Jan 58, 1306 CST

Ft. Churchill, Canada

METHOD: Rocket (AM N-C 6.03) and falling sphere

PROBABLE ERROR: <2%, 20-75 km; <5%, 76-91 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}	km	gm m^{-3}
20.9	72.1	56.8	.472
21.7	64.6	58.4	.377
22.5	56.9	60.0	.302
24.4	44.2	61.6	.249
26.8	31.6	63.2	.212
28.1	24.7	64.7	.182
29.4	18.5	69.3	(.086)
30.9	15.0	70.9	.0756
32.4	11.2	72.3	.0569
34.0	8.48	73.8	.0451
37.2	4.73	75.3	.0369
38.8	3.68	76.8	.0330
40.4	2.99	78.2	.0297
42.1	2.51	79.7	.0256
43.7	2.04	81.1	.0163
45.4	1.66	82.5	.0136
47.0	1.38	85.3	.00999
48.7	1.15	86.7	.00928
50.3	0.952	88.0	.00928
52.0	.824	89.4	.00565
53.6	.688	90.7	.00418
55.2	.570		

* A comparison of the sphere densities for 27 Jan 58 with grenade densities for the same rocket firing, and with the radiosonde data, suggests that the sphere density curve should be shifted upward by about 2 kilometers. Thus, e.g., the sphere density of 6.65 gm m^{-3} reported at 34 km would apply to a real altitude of 36 km.

21 Feb 58, 2002 CST

Ft. Churchill, Canada

METHOD: Rocket (NN 3.18F) with mass spectrometer

ERROR: From about 25% to factor of 2 or more, depending on rocket angle of attack.

THE DATA: Not reproduced here. Graph of 21 data points, 115 to 215 km, available in Meadows and Townsend, 1960 [40].

24 Feb 58, 0100 CST

Ft. Churchill, Canada

METHOD: Rocket (NN Aer 3.14 F) with pressure gages

PROBABLE ERROR: ± 45%

DATA SOURCES: Newell, 1960 [7]; La Gow and others, 1958 [38].

km	gm m^{-3}
202	$1.3 \pm 0.6 \times 10^{-7}$

24 Feb 58, 0135 CST

Ft. Churchill, Canada

METHOD: Rocket (AM N-C 6.37) with pressure gages

ERROR: Data are preliminary; revised data should become available fall 1960.

DATA SOURCE: Spencer and others, 1958 [36].

km	gm m^{-3}
54	(0.6)
60	(0.3)
62.5	(0.2)
65	(0.15)
67.5	(0.12)
70	(0.11)
72.5	(0.09)
75	(0.07)
77.5	(0.05)
80	(0.033)
82.5	(0.024)
85	(0.019)

4 Mar 58, 1330 CST

Ft. Churchill, Canada

METHOD: Rocket (AM N-C 6.05) and falling sphere

PROBABLE ERROR: < 2%, 20-75 km; < 5%, 76-91 km.

DATA SOURCE: Jones and others, 1959 [25].

km	gm m^{-3}	km	gm m^{-3}
20.6	71.4	58.7	.299
22.1	57.9	63.4	.172
23.0	51.3	64.9	.140
24.0	(43.)	66.4	.110
25.0	36.9	68.0	.0905
27.4	26.1	69.5	.0697
28.7	20.9	72.4	.0401
31.5	13.1	73.9	.0386
33.0	10.4	75.4	.0348
34.6	(7.3)	78.3	.0211
36.1	6.50	81.1	.0132
37.7	4.94	82.6	.0147
39.3	4.13	84.0	.0115
40.9	3.05	85.4	.0126
42.5	2.42	86.7	.00842
44.2	1.93	88.1	.0102
45.8	1.53	89.4	.00349
47.4	1.23	90.8	.00485
49.1	1.01		
50.1	0.813	Upleg data	
52.3	.664	(sel. levels)	
53.9	(.54)		
55.5	(.43)	60.5	(.21)
57.1	.367	76.4	.0250

23 Mar 58, 1207 CST

Ft. Churchill, Canada

METHOD: Rocket (NN Aer 3.19F) with mass spectrometer

ERROR: From about 25% to factor of 2 or more, depending on rocket angle of attack.

THE DATA: Not reproduced here. Graph of 15 data points 110 to 180 km, available in Meadows and Townsend, 1960 [40]. Data are provisional.

24 Mar 58, 1600 CST

Ft. Churchill, Canada

METHOD: Rocket (AM N-C 6.38) with pressure gages

ERROR: Data are preliminary; revised data should become available fall 1960.

DATA SOURCE: Spencer and others, 1958 [36].

km	gm m^{-3}
51	(0.6)
52.5	(0.5)
55	(0.4)
57.5	(0.3)
60	(0.21)
62.5	(0.15)
65	(0.11)
67.5	(0.075)
70	(0.053)
72.5	(0.042)
75	(0.027)
77.5	(0.018)
80	(0.013)
82.5	(0.009)
85	(0.0055)

31 Oct 58, 1400 CST

Ft. Churchill, Canada

METHOD: Rocket (NN Aer 3.15F) with pressure gages

ERROR: Maximum estimated at ± 30% at 100-188 km (Horowitz and others, 1959). 2% at 24 km increasing to 8% at 110 km (Ainsworth).

DATA SOURCES:
A. Ainsworth and others [37]
B. Horowitz and others [42]

km	A gm m^{-3}	B gm m^{-3}	km	A gm m^{-3}	B gm m^{-3}
24	43.4	(No data below 100 km)	74	.0345	
26	31.2		76	.0251	
28	23.1		78	.0186	
30	17.2		80	.0136	
32	12.7		82	.0102	
34	9.20		84	.00779	
36	6.75		86	.00597	
38	5.02		88	.00453	
40	3.72		90	.00338	
42	2.73		92	.00249	
44	2.00		94	.00180	
46	1.46		96	.00130	
48	1.05		98	9.48×10^{-4}	
50	0.790		100	6.86	4.9×10^{-4}
52	.607		105	3.20	
54	.455		110	1.54	1.1×10^{-4}
56	.344		120		2.5×10^{-5}
58	.267		130		6.7×10^{-6}
60	.207		140		3.0×10^{-6}
62	.164		150		1.8×10^{-6}
64	.129		160		1.2×10^{-6}
66	.100		170		8.6×10^{-7}
68	.0780		180		6.4×10^{-7}
70	.0605		188		5.2×10^{-7}
72	.0463				

12 Nov 58, 2140
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.52) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)*

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
28.3	20.0
29.8	15.4
31.8	11.9
33.8	9.14
35.8	7.05
37.8	5.44
39.8	4.21
41.8	3.32
43.8	2.57
45.8	1.98
47.8	1.52
49.8	1.17
51.8	.903
53.8	.703
55.8	.560
57.8	.443
58.8	.393

* Error in this sounding is possibly larger in layer 35-51 km.

14 Nov 58, 2110
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.53) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
29.8	18.0
30.3	15.4
32.3	11.4
34.3	8.43
36.3	6.28
38.3	4.70
40.3	3.53
42.3	2.67
44.3	2.05
46.3	1.59
48.3	1.24
50.3	.974
52.3	.764
54.3	.595
56.3	.461
58.3	.359
60.3	.282
62.3	.220
64.3	.170
66.3	.130
68.3	.0986

20 Nov 58, 0402
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.54) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
29.9	16.9
31.9	12.4
33.9	9.18
35.9	6.81
37.9	5.07
39.9	3.79
41.9	2.86
43.9	2.16
45.9	1.65
47.9	1.29
49.9	1.01
51.9	.794
53.9	.622
55.9	.488
57.9	.389
59.9	.307
61.9	.239
63.9	.184
65.9	.139
67.9	.104

21 Nov 58, 0039
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.55) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
28.3	22.8
29.8	16.7
31.8	12.3
33.8	9.12
35.8	6.80
37.8	5.09
39.8	3.82
41.8	2.89
43.8	2.20
45.8	1.68
47.8	1.30
49.8	1.03
51.8	.810
53.8	.637
55.8	.500
57.8	.391
59.8	.303
61.8	.234
63.8	.181

22 Nov 58, 1958
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.56) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}	km	gm m^{-3}
27.9	24.7	54.4	.583
28.4	21.1	56.4	.456
30.4	15.4	58.4	.359
32.4	11.3	60.4	.281
34.4	8.35	62.4	.218
36.4	6.21	64.4	.167
38.4	4.65	66.4	.128
40.4	3.50	68.4	.0969
42.4	2.64	70.4	.0741
44.4	2.01	72.4	.0573
46.4	1.56	74.4	.0435
48.4	1.22	76.4	.0325
50.4	.950	77.4	.0278
52.4	.744		

23 Nov 58, 0306
150°E Meridian Time

Guam

METHOD: Rocket (SS Aer 12.57) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz)

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
22.1	65.9
23.6	46.7
25.6	33.4
27.6	24.1
29.6	17.6
31.6	12.9
33.6	9.54
35.6	7.11
37.6	5.34
39.6	4.04
41.6	3.08
43.6	2.39
45.6	1.88
47.6	1.48
49.6	1.16
51.6	.904
53.6	.700
55.6	.538
57.6	.409
58.6	.360

25 Nov 58, 0327
150°E Meridian Time

Guam

METHOD: Rocket (SS N-C 6.58) - grenade

PROBABLE ERROR: < 3% (estimate by Quiroz).

DATA SOURCE: Nordberg and Stroud, 1961 [46] (tabular data provided by Nordberg).

km	gm m^{-3}
28.0	24.4
29.5	17.7
31.5	13.0
33.5	9.61
35.5	7.16
37.5	5.37
39.5	4.05
41.5	3.07
43.5	2.38
45.5	1.88
47.5	1.49
49.5	1.16
51.5	.898
53.5	.702
35.5	.549
57.5	.428
59.5	.336
61.5	.264
63.5	.205
65.5	.161
67.5	.122
69.5	.0899
71.5	.0648
73.5	.0462
74.5	.0392

DEPARTMENT OF THE AIR FORCE

AIR FORCE COMBAT CLIMATOLOGY CENTER (AFWA)
ASHEVILLE, NORTH CAROLINA 28801-5002

20 July 2005

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4. ADB130894 – Directory of climatic databases available from OL-A, USAFETAC, Jan. 1996.

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